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Equilibrium Configuration of a Rectangular Strip of Net Subjected to a Uniform Current

By
TASAE KAWAKAMI

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On the Mechanical Characters of the Drag-Net

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KYOTO

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Equilibrium Configuration of a Rectangular Strip of Net Subjected to a Uniform Current

By

Tasae Kawakami*

With 1 Table and 1 Textfigure

(Received Dec. 14, 1954)

In the analytical treatment of mechanical problems of fishing nets, it may be of fundamental importance to get an accurate knowledge regarding the equilibrium configuration of a strip of net and the distribution of tension along it, when its both ends are supported in a uniform current of water. As to the hydrodynamic force of relative velocity of current acting on a unit area of plane net, we have Tauti's law[1], in which it is assumed that the force acting on a unit length of netting cord is proportional to the sine of the angle between its longitudinal axis and the direction of the flow and is perpendicular to the axis. According to Tauti's law, a numerical table for determining the configuration and tension of a rectangular strip of net supported by both ends in a uniform current was computed.

Suppose that a long narrow rectangular strip of net of a constant width h is supported by both ends in a uniform current. Let the net be constructed of homogeneous mesh of $2L$ in stretched measure woven with a netting cord of diameter D, and let a constant rate of slack be allowed on the edge line so as to make an angle 2φ between two adjacent arms. The problem is to find the equilibrium configuration and distribution of tension of the net which will appear due only to the resistance of the stream.

If all the bisectors between two adjacent arms of the net lie in a same plane or in parallel planes which include the velocity vector of the current, following Tauti's law and neglecting the resistances of knots, the tangential component K_t and the normal component K_n of the resisting force is expressed as follows :

$$K_t = K \sin^2\varphi \cos\theta ,$$

$$K_n = K \sin\theta ,$$

where θ is the angle of inclination of the plane of the net, measured positive

* Laboratory of Applied Physics.

unticlockwise from the direction of the current, and K is the resisting force acting on a unit area of the net when it is placed normal to the current, and is expressed as

$$K = k\, U^2\, \frac{D}{L} \sec\varphi \operatorname{cosec}\varphi, \tag{1}$$

k being a constant corresponding to the drag coefficient of the netting cord (i.e. $k = C_D\rho/2$ in ordinary hydrodynamical expressions). Since all the states of the net may be fixed two-dimensionally, let us choose rectangular coordinates (x, y), the origin, O, of which is located at a point of the edge line of the net, let y-axis be parallel to the stream line, measured positive upstream as shown in Figure 1.

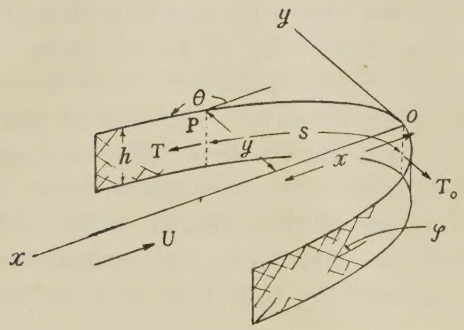

Figure 1.

Let s be the arc length along the edge line of the net, measured from the origin to any point P (x, y) and let T be the tension of the net at the point P, then neglecting the apparent weight or buoyancy of the net in water, the equation of equilibrium can be written as

$$\frac{dT}{ds} = K\, h \sin^2\varphi \cos\theta, \tag{2}$$

$$T\, \frac{d\theta}{ds} = K\, h \sin\theta, \tag{3}$$

where the angle θ is measured positive unti clockwise from the direction of the current to the direction of increasing s. If we introduce the following dimensionless quantities :

$$\tau = \frac{T}{T_o}, \qquad \sigma = \frac{Kh}{T_o}\, s, \qquad \xi = \frac{Kh}{T_o}\, x, \qquad \eta = \frac{Kh}{T_o}\, y,$$

where T_o signifies the tension of the net at the origin. The differential equations (2) and (3) may be integrated with the condition that

$$\tau = 1,\ \sigma = 0\ (\xi = 0,\ \eta = 0),\ \text{for}\ \theta = \frac{\pi}{2}$$

to give

$$\tau = (\sin\theta)^{-\sin^2\varphi}, \tag{4}$$

$$\sigma = \int_{\frac{\pi}{2}}^{\theta} (\sin\theta)^{-(1+\sin^2\varphi)}\, d\theta, \tag{5}$$

$$\xi = \frac{1}{\sin^2\varphi}(\tau-1), \tag{6}$$

$$\eta = \int_{\frac{\pi}{2}}^{\theta} \tau \, d\theta. \tag{7}$$

Next, let a be the area enclosed by the x-axis, the arc of the net and the straight line parallel to the y-axis, $x = x$, then write

$$\alpha = \left(\frac{Kh}{T_o}\right)^2 a,$$

we have

$$\alpha = \int_o^{\xi} \eta \, d\xi = \xi \, \eta - \int_{\frac{\pi}{2}}^{\theta} \tau \, \xi \, d\theta. \tag{8}$$

The numerical integration given by the equation (5) and (6) were carried out by the use of SIMPSON'S one-third rule with interval of 5° for the range from 90° to 150°, thereafter the interval was reduced by degrees to 10′ at 170°. The results of computations are compiled in annexed Table, which will facilitate the determination of the configuration and tension of a rectangular strip of net supported in a uniform current.

The author wishes to express his hearty thanks to Miss E. ARAKI who carried out some of the computations required.

Reference

1. TAUTI, M.; The force acting on the plane net in motion through the water. Bull. Jap. Soc. Sci. Fish. 3 (1), 1934, 1.

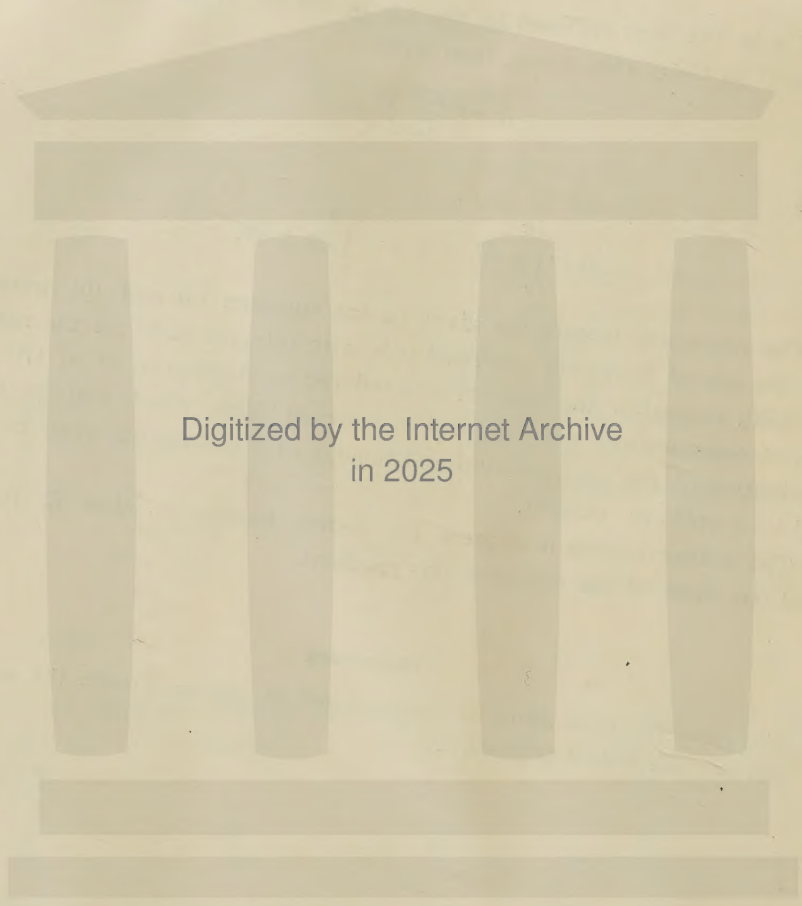

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Table for Computing the Configuration of Net.

θ \ φ	τ			σ			ξ			η			α		
	30°	45°	60°	30°	45°	60°	30°	45°	60°	30°	45°	60°	30°	45°	60°
90°	1.	1.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
95	1.00095	1.00191	1.00286	0.0874	0.0874	0.0875	0.00382	0.00382	0.00382	0.0873	0.0873	0.0873	0.000222	0.000222	0.000223
100	383	768	1.01155	1757	1759	1761	1534	1537	1540	1748	1750	1752	1788	1794	1799
05	870	1.01748	2634	2656	2664	2672	3482	3497	3512	2626	2633	2641	6107	6149	6192
10	1.01567	3159	4776	3583	3601	3620	6269	6318	6368	3509	3527	3545	0.014716	0.014902	0.015088
15	2490	5042	7657	4546	4585	4624	9960	0.10084	0.10210	4399	4435	4472	2938	2996	3056
20	3662	7457	1.1139	5561	5630	5701	0.14646	14914	15189	5298	5362	5427	5217	5370	5529
25	5114	1.1049	1614	6641	6758	6878	2045	2098	2152	6209	6312	6419	8568	8918	9287
30	6890	1425	2213	7808	7994	8189	2756	2851	2950	7134	7299	7467	0.13318	0.14053	0.14839
35	9051	1892	2968	9087	9375	9679	3620	3784	3958	8076	8309	8555	19903	2135	2292
40	1.1168	2473	3930	1.0514	1.0950	1.1417	4673	4946	5240	9038	9371	9727	2892	3163	3466
45	1491	3204	5172	2140	2792	3504	5963	6408	6897	1.0027	1.0490	1.0994	4124	4618	5186
50	1892	4142	6818	4042	5015	6103	7568	8284	9091	1046	1682	2387	5818	6701	7755
53	2183	4841	8081	5364	6607	8019	8730	9683	1.0774	1676	2440	3299	7139	8389	9919
56	2522	5680	9634	6868	8464	2.031	1.0088	1.1360	2646	2323	3238	4285	8769	1.0544	1.2778
59	2925	6705	2.159	8611	2.068	314	1698	3409	5453	2989	4085	5362	1.0809	3346	6647
62	3412	7989	413	2.068	341	672	3649	5978	8837	3678	4992	6556	3411	7084	2.205
65	4020	9656	756	322	689	3.150	6080	9313	2.341	4395	5976	7904	8827	2.225	994
66	4259	2.033	899	420	828	347	7035	2.066	532	4642	6325	8398	8212	443	3.341
67	4520	108	3.062	528	983	570	8082	217	749	4893	6686	8917	9758	692	745
68	4809	193	248	646	3.156	824	9237	386	997	5149	7061	9468	2.149	978	4.222
69	5130	289	464	777	353	4.118	2.052	579	3.285	5410	7452	2.005	346	3.310	791
170	5491	400	717	924	577	462	196	799	623	5677	7861	068	570	700	5.480
71	5901	528	4.020	3.090	838	871	360	3.057	4.027	5951	8291	135	829	4.165	6.329
72	6372	681	389	281	4.146	5.368	549	361	518	6233	8745	209	3.133	729	7.396
73	6925	865	848	504	517	986	770	729	5.131	6523	9228	289	495	5.427	8.774
74	7587	3.093	5.440	770	977	6.780	3.035	4.186	920	6824	9747	379	937	6.318	10.616
75	8405	387	6.234	4.099	5.568	7.845	362	775	6.979	7138	2.031	480	4.492	7.498	13.190
175°20′	8724	506	564	227	807	8.287	490	5.012	7.419	7246	051	517	712	982	14.290
40′	9073	638	939	367	6.071	787	629	276	918	7356	072	556	954	8.526	15.556
176°	9458	786	7.367	522	369	9.360	783	572	8.490	7468	094	598	5.222	9.144	17.029
20′	9886	954	863	693	706	10.023	954	909	9.151	7583	116	642	521	852	18.762
40′	2.036	4.147	8.445	885	7.092	800	4.146	6.294	927	7700	140	690	859	10.672	20.83
177°	091	371	9.139	5.103	541	11.727	363	742	10.852	7820	164	741	6.245	11.637	23.34
20′	153	636	982	353	8.072	12.853	613	7.272	11.976	7943	191	796	691	12.791	26.46
40′	226	956	11.033	645	712	14.255	905	912	13.378	8070	218	857	7.218	14.201	30.42
178°	314	5.333	12.385	995	9.506	16.059	5.255	8.706	15.180	8202	248	925	852	15.975	35.63
10′	364	591	13.220	6.199	983	17.173	458	9.182	16.293	8270	264	962	8.223	17.048	38.91
20′	422	864	14.199	427	10.528	18.479	686	727	17.598	8840	281	2.002	640	18.288	42.80
30′	486	6.181	15.366	685	11.163	20.04	944	10.361	19.155	8411	298	045	9.115	19.740	47.51
40′	560	556	16.785	982	913	21.93	6.242	11.111	21.05	8485	317	092	663	21.47	53.31
50′	647	7.008	18.553	7.330	12.818	24.29	589	12.016	23.40	8560	337	143	10.307	23.58	60.66
179°	751	570	20.83	746	13.942	27.32	7.005	13.139	26.43	8638	358	200	11.081	26.21	70.28
10′	880	8.292	23.88	8.259	15.386	31.39	518	14.584	30.50	8718	381	265	12.038	29.64	83.41
20′	3.045	9.271	28.23	920	17.344	37.19	8.179	16.541	36.30	8804	406	341	13.277	34.32	102.60
30′	272	10.704	35.02	9.828	20.21	46.25	9.087	19.408	45.37	8895	435	432	14.989	41.26	133.30
40′	621	13.111	47.47	11.224	25.02	62.85	10.483	24.22	61.96	8995	470	550	17.634	53.07	191.27
50′	4.306	19.867	79.84	13.965	38.54	106.00	13.224	37.73	105.12	9109	514	726	22.86	86.71	348.1
180°	∞	∞	∞	∞	∞	∞	∞	∞	∞	1.9276	2.622	4.654	∞	∞	∞

edge with sinkers connected with lead line. These lines were fastened on each side of a vertical spreader at the ends of the wings. A schematic sketch of the whole net is shown in Figure 1.

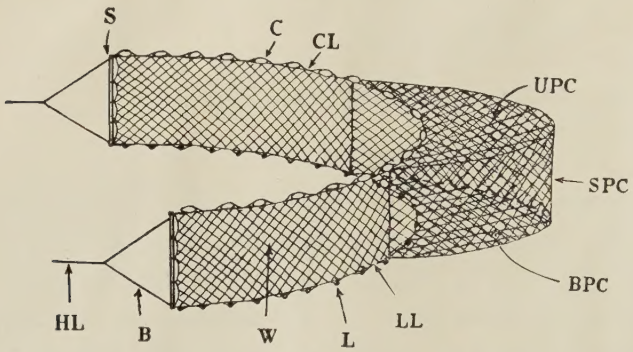

Figure 1. Experimental model net. Key:- HL, Hauling line; B, Bridle; S, Spreader; W, Wing; C, Float; CL, Cork line; L, Sinker; LL, Lead line; SPC, Side piece of the cod end; UPC, Upper piece of the cod end; BPC, Bottom piece of the cod end.

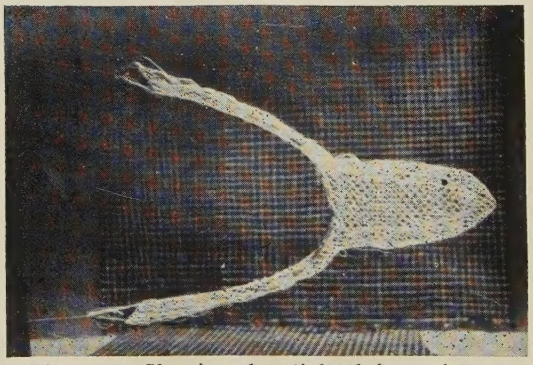

Figure 2. Showing the slight deformation of the side piece of the cod end in actual operation.

If the wings as well as the side piece of the cod end assume the ideal configuration as was mentioned above, and if the upper and bottom pieces of the cod end keep the parallel flat planes in practical operation, a comparatively simple mathematical treatment may be possible for evaluating the various mechanical relations. Figure 2 shows an example of the actual view of a model net of this type operating in the experimental tank. As it indicates, the side piece of the cod end gets out of its ideal shape, inflating horizontally, although the wings keep their expected form. But in the following analysis, for simplicity's sake, let us assume that the whole net assumes the ideal form.

III. Theoretical considerations

Since the geometrical configuration and the mechanical action may be symmetrical about the centre line, only the top view of the starboard side of the net is illustrated in Figure 3, provided that the whole net assumes the ideal form. In the figure, lengths, angles and tensions at various parts of the net are desig-

nated.

Let T_w be the tension at the front end, S, of the wing or the tension of the warp, and let T_{cw}, T_c and T_{wc} be respectively the tensions of the wing, that of the side piece of the cod end and the sum of tensions of the cork and the lead lines at the point J, where the wing joins the cod end. Let T_{co} be the tension at the centre, O_c, of the side piece of the cod end. Next, suppose that a long strip of imaginary net of the same webbing as the wing is subjected freely to a homogeneous current by supporting both ends so that a part of the imaginary net may coincide exactly with the actual wing, then the imaginary net may assume an ideal form which is represented by the dotted line in Figure 3. Designate

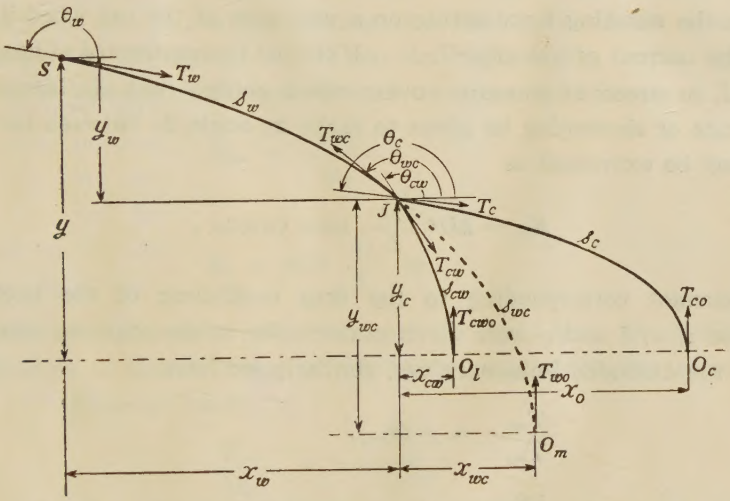

Figure 3. The schematic representation of the starboard side of the experimental net. Dotted line represents the extended imaginary part of the wing.

the imaginary part of net from the point J to the point O_m where the imaginary net becomes perpendicular to the stream line as "extended imaginary net" in the following. Let s_{wc} be the arc length measured along the extended imaginary net let T_{wo} be its tension at the point O_m. As to angles, let us measure positive unticlockwise from the direction of current to any direction; let θ_w be the angle of net at the front end of the wing, and θ_c, θ_{cw} and θ_{wc} be respectively the angle of side piece of the cod end, the angle of the cork (or lead) line and the angle of imaginary net at the point J. Next, choose the x-axis parallel to the stream line and y-axis perpendicular to it, then designate the length of each part in its respective directions as shown in the figure.

As to the shape and tension of the wing, the following relations may hold

immediately from the results of analysis discussed in the preceding paper[3] of the author;

$$\frac{T_w}{T_{wo}} = \tau\ (\theta_w), \tag{1}$$

$$\frac{hK_w}{T_{wo}}\ (s_w + s_{we}) = \sigma\ (\theta_w), \tag{2}$$

$$\frac{hK_w}{T_{wo}}\ (x_w + x_{we}) = \xi\ (\theta_w), \tag{3}$$

$$\frac{hK_w}{T_{wo}}\ (y_w + y_{we}) = \eta\ (\theta_w), \tag{4}$$

where K_w is the resisting force acting on a unit area of the net when it is placed normal to the current of velocity U. If the net be constructed of homogeneous meshes of $2L$ in stretched measure woven with a netting cord of diameter D, and a constant rate of shortening be given to make an angle 2φ between two adjacent arms, K_w may be expressed as

$$K_w = kU^2\ \frac{D}{L}\ \sec\varphi\ \mathrm{cosec}\varphi\ ,$$

k being a constant corresponding to the drag coefficient of the netting cord. The functions τ, σ, ξ and η were given numerically in the previous paper[3].

As to the extended imaginary net, similarly we have

$$\frac{T_{we}}{T_{wo}} = \tau\ (\theta_{we}), \tag{5}$$

$$\frac{hK_w}{T_{wo}}\ s_{we} = \sigma\ (\theta_{we}), \tag{6}$$

$$\frac{hK_w}{T_{wo}}\ x_{we} = \xi\ (\theta_{we}), \tag{7}$$

$$\frac{hK_w}{T_{wo}}\ y_{we} = \eta\ (\theta_{we}). \tag{8}$$

Next, with regard to the cod end, if no mechanical interference between the side piece and the upper or bottom piece can be assumed, following relation may hold for the tension and configuration of the side piece;

$$\frac{T_e}{T_{eo}} = \tau\ (\theta_e), \tag{9}$$

$$\frac{hK_e}{T_{eo}}\ s_e = \sigma\ (\theta_e), \tag{10}$$

$$\frac{hK_c}{T_{co}} x_c = \xi(\theta_c), \tag{11}$$

$$\frac{hK_c}{T_{co}} y_c = \eta(\theta_c), \tag{12}$$

where K_c is the resisting force acting on a unit area of the side piece when it is supported perpendicularly to the current.

Strictly speaking, the force acting on the cork or lead lines at the front edge of the cod end may be too complicated to treat analytically. Accordingly it is assumed here, for simplicity's sake, that the whole resistances of the npper or bottom piece of the cod end are acting uniformly throughout the whole length of the lines at the entrance of the cod end. Let $2a$ be the area of the upper or bottom piece and K_t the force acting on a unit area of the net when it is placed parallel to the current. Then the forces acting on the both lines are assumed to be parallel to the current and to be averaged as

$$K_{cw} = \frac{aK_t}{s_{cw}}, \tag{13}$$

where

$$K_t = kU^2 \frac{D}{L} \tan \varphi.$$

If this force acts uniformly upon the cork (or lead) line, its configuration and the distribution of tension along it may be the same as in the case of common catenary. Thus we have

$$\frac{T_{cw}}{T_{cwo}} = \operatorname{cosec} \theta_{cw}, \tag{14}$$

$$\frac{K_{cw}}{T_{cwo}} s_{cw} = -\cot \theta_{cw}, \tag{15}$$

$$\frac{K_{cw}}{T_{cwo}} x_{cw} = \operatorname{cosec} \theta_{cw} - 1, \tag{16}$$

$$\frac{K_{cw}}{T_{cwo}} y_{cw} = \log \tan \frac{\theta_{cw}}{2}. \tag{17}$$

In addition, the equilibrium conditions at the point J can be written as follows ;

$$T_{wc} \cos \theta_{wc} = T_{cw} \cos \theta_{cw} + T_c \cos \theta_c, \tag{18}$$

$$T_{wc} \sin \theta_{wc} = T_{cw} \sin \theta_{cw} + T_c \sin \theta_c. \tag{19}$$

Now we have obtained nineteen equilibrium equations (1)~(19) in which twenty eight variables are appeared. If, however, the design of the net and

the speed of the current are given, eight parameters h, a, K_w, K_c, K_t, s_w, s_c and s_{cw} may be fixed. Therefore, the relation between θ_w, T_w and $y = y_w + y_c$, for which we are seeking, may be obtained numerically by solving these transcendental equations simultaneously.

IV. Numerical solution

In order to get the solution, the following numerical procedure may be employed. On eliminating the variables which are out of the present problem, and on rearranging the equations, there results

$$T_w = hK_w (s_w + s_{wc}) \frac{\tau(\theta_w)}{\sigma(\theta_w)} , \tag{20}$$

$$y_w + y_{wc} = (s_w + s_{wc}) \frac{\eta(\theta_w)}{\sigma(\theta_w)} , \tag{21}$$

$$T_{wc} = hK_w s_{wc} \frac{\tau(\theta_{wc})}{\sigma(\theta_{wc})} , \tag{22}$$

$$y_{wc} = s_{wc} \frac{\eta(\theta_{wc})}{\sigma(\theta_{wc})} , \tag{23}$$

$$T_w = T_{wc} \frac{\tau(\theta_w)}{\tau(\theta_{wc})} , \tag{24}$$

$$T_c = hK_c s_c \frac{\tau(\theta_c)}{\sigma(\theta_c)} , \tag{25}$$

$$y_c = s_c \frac{\eta(\theta_c)}{\sigma(\theta_c)} , \tag{26}$$

$$T_{cw} = -aK_t \sec \theta_{cw} , \tag{27}$$

$$y_c = s_{cw} \frac{\log \tan (\theta_{cw}/2)}{-\cot \theta_{cw}} , \tag{28}$$

$$\cot \theta_{wc} = \frac{T_{cw} \cos \theta_{cw} + T_c \cos \theta_c}{T_{cw} \sin \theta_{cw} + T_c \sin \theta_c} . \tag{29}$$

In practical computation, if Newton's law for hydrodynamic resistance be tennable, it will be recommendable to devide all parameters designating the forces and tensions by kU^2 for the purpose of eliminating the influence of the current speed.

To begin with, corresponding to various numerical values of θ_c which are previously pressumed at an arbitrary moderate interval, say 10′ or 5′, compute the values of (T_c/kU^2) and y_c by using the equations (25) and (26) respectively. Next, for each value of θ_c, determine the value of θ_{cw} which satisfies the equation (28). Then we can compute successively the value of (T_{cw}/kU^2) by means

of the equation (27), the value of θ_{wc} by means of the equation (29), the value of (T_{wc}/kU^2) by means of equation (18) or (19), the value of s_{wc} by means of the equation (22), and lastly the value of y_{wc} by means of the equation (23), for each value of θ_c. Next, on eliminating T_w from the equations (20) and (24) we get

$$\sigma(\theta_w) = (s_w + s_{wc}) \frac{hK_w}{T_{wc}} \tau(\theta_{wc}), \qquad (30)$$

by which we obtain the value of $\sigma(\theta_w)$ accordingly the value of θ_w. Other unknown variables corresponding to these values may be obtained readily.

As has been seen from the above treatment, it may be supposed that the stationary form of this type of net which lacks its square and belly, when it is subjected to a homogeneous current, may be settled irrespective of its speed.

V. Experiment

A series of experiments was carried out in the experimental water tank of circulation type installed in the physical laboratory of this department. The dimensions of the model net used were as follows ;

$$D = 0.045\text{cm.}, \quad L = 0.9\text{cm.}, \quad (D/L) = 0.05, \quad \varphi = 45°,$$

$$h = 11\text{cm.}, \quad s_w = 29\text{cm.}, \quad s_{cw} = 4\text{cm.}, \quad s_c = 21\text{cm.},$$

$$K_w = K_c = 0.1kU^2, \quad K_t = 0.05kU^2.$$

The numerical computation given in the preceding section may be carried out as shown in Table 1. The relation between T_w, y and θ_w for which we are seeking is shown in Figure 4.

Table 1.

θ_c	T_c/kU^2	y_c	θ_{cw}	T_{cw}/kU^2	θ_{wc}	T_{wc}/kU^2
178°45′	12.68	3.950	105°33′	12.23	142°54′	20.00
47	12.65	3.900	111 26	8.98	151 43	18.11
50	12.62	3.825	118 50	6.80	158 40	17.57
179 00	12.55	3.555	133 42	4.75	167 01	16.26
10	12.45	3.250	144 32	4.03	170 55	15.94
20	12.34	2.915	152 46	3.69	173 19	15.75
30	12.22	2.530	159 58	3.49	175 13	15.62
40	12.10	2.070	166 09	3.38	176 44	15.41

θ_c	s_{wc}	y_{wc}	θ_w	T_w/kU^2	$'y_w+y_{wc}$	y
178°45′	16.45	14.14	168°21′	34.50	24.20	14.01
47	17.96	13.70	171 59	33.45	21.30	11.50
50	19.67	13.47	174 07	33.10	19.10	9.45
179 00	20.90	11.68	176 41	32.05	15.00	6.88
10	21.95	10.50	177 43	31.90	12.82	5.57
20	22.75	9.45	178 21	31.60	11.15	4.62
30	23.45	8.37	178 50	31.55	9.59	3.75
40	24.00	7.17	179 12	31.35	7.98	2.88

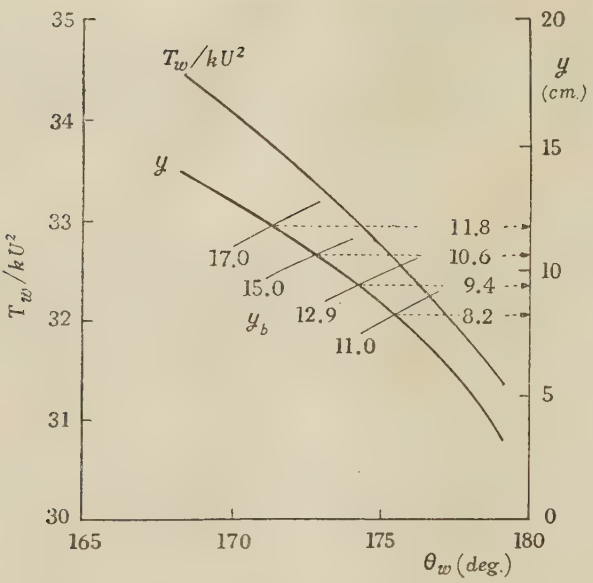

Figure 4. Theoretical relations of T_w and y to θ_w. Thin curves interesecting the y-curve represent the relations expressed by the equation (35) for various values of y_b.

The net was hauled with hauling lines which were attached to the top and bottom of the spreader by short bridles. The wings were kept appart by being attached the warps to a horizontal spreading beam, that is a kind of beam trawl. The length, $2y_b$, between these two connection points on the beam can be controlled arbitrarily. The hauling lines were then run to a single line or a warp. Schematic sketch of the arrangement is shown in Figure 5. Denote the length along the hauling line from the vertical spreader to the connection point on the horizontal spreading beam by l, which was kept constant (l = 35cm.) throughout the present experiments.

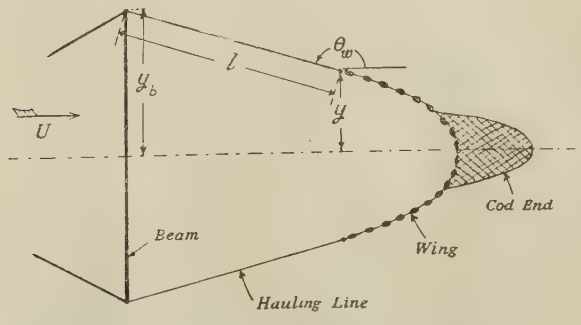

Figure 5. Experimental arrangement of the model net.

The speed, U, of the current was varied within the range from 7 to 40cm./sec. so that corresponding REYNOLDS' number, R_e, formed with the diameter of the netting cord amounted to 30~180. In the experiments, the horizontal spread $2y = 2(y_w + y_c)$, the speed of the current, U, and the tension, T_d, of the warp were measured for various values of y_b and U. The results are summerized in the first, second and third columns in Table 2.

Table 2.

U cm./sec.	T_d dyn	$2y$ cm.	C_D	R_e
y_b=11cm.				
26.8	314 $\times 10^2$	16.5	0.94	117
18.7	181	16.2	1.19	84
11.3	73.5	17.0	1.37	51
9.1	49.0	17.0	1.42	41
9.7	59.0	—	1.54	44
7.2	30.0	17.0	1.38	32
y_b=12.9cm.				
34.0	494	18.0	0.91	153
25.9	327	19.0	1.10	116
26.0	326	18.8	1.06	117
21.0	228	19.0	1.18	95
17.4	164	19.0	1.26	78
11.7	86	19.0	1.52	53
y_b=15.0cm.				
40.8	718	21.0	0.91	184
34.4	601	20.8	1.15	155
29.6	470	21.0	1.25	133
24.1	323	21.5	1.29	108
20.1	235	21.5	1.37	90
13.5	110	21.0	1.43	61
8.7	62	21.0	2.07	39
y_b=17cm.				
36.4	635	23.0	1.05	166
30.0	508	23.5	1.30	135
27.5	386	23.5	1.14	124
23.1	296	23.0	1.27	104
17.3	184	24.0	1.45	78
12.5	90.2	23.5	1.34	56
8.4	54.0	23.5	1.89	38
6.7	32.4	—	1.77	30

For equilibrium, if we neglect the slight resistances acting on the hauling lines, the following relation may hold approximately ;

$$\frac{T_d}{2} = -T_w \cos\theta_w + F', \tag{31}$$

$$y = y_b - l \sin\theta_w \tag{32}$$

where F' is the sum of the resistances caused by various accessories such as spreading beam, floats etc. Since the spreading beam was made of slender bamboo rod of 0.4cm. in diameter and 35cm. in length, its resistance approximates to $3.5\,U^2$. The float was made of spindle shaped wooden piece the dimension of which was about $0.4 \times 0.7 \times 1.5\text{cm}^3$. Since ten floats were attached to the half side of the net, the sum of resistances of the floats including the sinkers is roughly estimated to $3.0U^2$. Let us assume, therefore, that $F' = 3.5\,U^2 + 3.0U^2 = 6.5U^2$. Then the value of k may be given by

$$k \equiv \frac{C_D}{2} = \left(\frac{T_d}{2U^2} - 6.5\right) \Big/ \left(-\frac{T_w}{kU^2}\cos\theta_w\right).$$

The relation of the drag coeficient, C_D, to REYNOLDS' number thus obtained is shown in Table 2, and plotted in Figure 6, in which the heavy line shows the same relation for the case of infinite circular cylinder which has been investigated by many authorities. Generally speaking, both plots, though appeared to have a slightly different slope, show a rather good coincidence in spite of the complexity of the experimental object. It seems to the author that the difference in slope of the curve may be ascribed to the slight deformation of the net according to the current speed. Since the values of y_b and l were given in the experiments, we can determine numerically the values of y and θ_w which satisfy the equation (35) as well as the theoretical relation shown in Figure 5 simultaneously. A graphycal method of determination of theoretical values of y for various of y_b is shown in the same figure. The observed values of y are plotted against y_b in Figure 7 together with the theoretical relation thus obtained. The coincidence of both plots seems to be satisfactory, if we take the accuracy of the experiment into account.

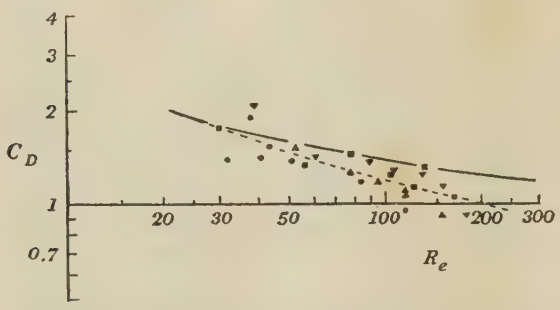

Figure 6. The relation of drag coefficient vs. REYNOLDS' number for netting cord obtained by the experiments is compared with that for infinite circular cylinder. Length y_b of the beam : ●, 11.0 ; ▲, 12.9 ; ▼, 15.0 ; ■, 17.0cm.

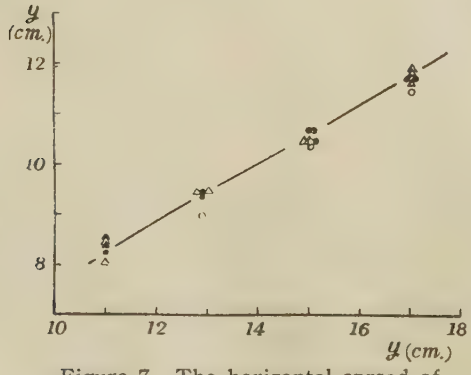

Figure 7. The horizontal sprsad of the wings obtained by the experiments is compared with the theoretical value. Current velocity U :- ▲, 0~10 ; △, 10~20 ; ●, 20~30 ; ○, >30cm./sec.

VI. Concluding remark

The design of the model net with which we have dealt here may, of course, be rather simple as compared with practical gears, but it seems to be of some value to investigate such an ideal case in elucidating the actual mode of mechanical characters of this type of gear, because the essential mechanical properties of the practical net may be maintained even in such a schematic model. A further

investigation in this line is now in progress in the hope that we will be able to throw some light on the design of drag-nets or trawl nets and on their manipulation as well.

VII. Acknowledgments

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